3-2-5

LOW-NOISE SMALL-SIGNAL AMPLIFIER

D. Neuf and P. Lombardo

23 February 1963

Prepared under Navy, Bureau of Ships

Contract NObsr-87556

Interim Report No. 2

25 October 1962 to 25 January 1963

CUTLER-HAMMER
AIRBORNE INSTRUMENTS LABORATORY
DEER PARK, LONG ISLAND, NEW YORK
AIL DIVISION

LOW-NOISE SMALL-SIGNAL AMPLIFIER

D. Neuf and P. Lombardo

23 February 1963

Prepared under Navy, Bureau of Ships

Contract NObsr-87556

Interim Report No. 2

25 October 1962 to 25 January 1963

AIRBORNE INSTRUMENTS LABORATORY
A DIVISION OF CUTLER-HAMMER, INC.
Deer Park, Long Island, New York

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

ABSTRACT

High gain (10 db) low-noise amplification (1.6 db) over a 20-percent bandwidth has been achieved with a single-diode mount. At the present time, two such mounts are being cascaded to determine what overall performance can be achieved over a 40-percent bandwidth. Amplification over a 40-percent bandwidth has been obtained from a balanced-diode mount. The noise factor of this amplifier is about 2.5 db at 2500 Mc; however, it is hoped that, through the use of diodes with higher cut-off frequencies, this noise figure can be reduced to less than 2 db.

I. STATEMENT OF PURPOSE

Contract NObsr-87556, Project SR-008-03-01, Task 9391, requires that research and development effort be conducted in the field of low-noise amplifiers with emphasis on four sample devices having the following specifications:

Frequency	Within S-band (2 to 4 Gc)
Gain	15 db (minimum)
Bandwidth	40 percent (minimum)
Noise Factor	2 db (maximum)
Dynamic Power Range	70 db
Cryostatic Cooling	None

II. TECHNICAL DISCUSSION

A. SINGLE-DIODE MOUNT

During the past quarter, engineering effort on the single-diode mount has progressed well. Figure 1 illustrates the gain, bandwidth, and noise figure of a single-stage mount that used a Microwave Associates diode. This data indicates that gain over a 40-percent bandwidth could be achieved with four such stages arranged in two cascaded pairs. Each pair would be stagger-tuned to cover the 2 to 3 Gc range.

The gain-bandwidth product described by Figure 1 is the largest yet obtained from a single-diode mount built at AIL. The most significant factors producing this wide-band performance resulted from the use of:

1. Double-section $\lambda/4$ transformer in the signal circuit,
2. Double-tuned signal circuit,
3. Wide-band circulator.

At present, effort is being directed toward building another stage with a 500-Mc bandwidth centered at about 2950 Mc. Figure 2 shows the type of performance that could be expected if two such stages were cascaded with staggered center frequencies. Figure 3 shows how the amplifiers could be connected. Generally, lower frequency range amplifiers (2.0 to 2.5 Gc) will have a lower noise figure than the higher range (2.5 to 3.0 Gc) because noise factor is proportional to

$$\left(1 + \frac{f_1}{f_2}\right)$$

where

f_1 = signal frequency,
f_2 = idler frequency.

To the second-stage noise figure must be added the first stage circulator loss and any reflection loss occurring in the amplifier itself. Therefore the amplifier of the low frequency range would be used as the second stage so that the overall noise figure would be relatively constant as a function of frequency. The extreme case occurs at 2.0 Gc. At this point, the overall noise factor, assuming perfect reflection (0 db) by the first stage, would be:

$$1.4 + 0.6 = 2.0 \text{ db}$$

where

1.4 = noise factor of second stage,
0.6 = loss through first-stage circulator.

At 3.0 Gc, the overall noise factor would be about equal to the first-stage noise factor since the gain of this stage is relatively high. Assuming a linear increase in noise factor with frequency, an overall noise figure of about 2 db could be expected.

Further tests will be made on the single-diode mount to widen its bandwidth by using a lower-impedance idler-return stub. This would lower the Q of the circuit and provide wider bandwidth capabilities at the expense of a slight decrease in gain-bandwidth product.

B. BALANCED-DIODE MOUNT

Gain (4 db) over a 40-percent bandwidth (2 to 3 Gc) has been achieved with a modified balanced-diode mount that has double-tuning in the signal circuit. However, further improvements must be made to reduce the noise factor (2.5 db) of this amplifier.

Generally, when trying to achieve wide-band amplification, all stray capacitances must be reduced to a minimum. Therefore, the idler cavity of the balanced-diode mount was enlarged in the vicinity of the diodes to reduce the capacitive loading.

In addition, double-tuning was used in the signal circuit. Figure 4 shows two response curves obtained from the balanced-diode mount. A spot noise factor was measured at 2.5 Gc under both high- and low-gain pumping conditions. Since the observed 1.5-db noise factor at 2.5 Gc seems to be below the 2 db specified by the contract, the solution appears to be to construct several identical stages to raise the gain. However, the contribution of each stage of a cascade to the overall noise factor must be considered. The overall noise factor of a series of amplifiers is

$$F_{1n} = F_1 + \frac{F_2-1}{G_1} + \frac{F_3-1}{G_1G_2} + \cdots\frac{F_n-1}{G_1G_2\ldots G_{n-1}}$$

If a large number of identical amplifiers, each having the same noise factor and gain, were cascaded, it can be shown that this overall noise factor expression reduces to

$$F_{overall} = \frac{G_1F_1-1}{G_1-1}$$

where

G_1 = gain of each amplifier as a power ratio,

F_1 = noise factor of each amplifier as a power ratio,

$F_{overall}$ = noise factor of an infinite cascade of the same amplifier.

Thus, the use of, for example, five cascaded 3-db gain stages, each having a 1.5-db noise factor, would yield an acceptable gain; however, the overall noise factor would be far greater (2.6 db) than the noise factor of each individual stage. The increase in noise factor between the high- and low-gain curves shown in Figure 4 is caused by "anomalous reverse current" in the varactor diodes (Appendix). Anomalous current, a phenomenon usually associated with large pumping voltages, can severely degrade noise factor because of the high resultant peak forward and reverse currents, which, in turn, produce added shot noise.

The presence of anomalous current is not easily detected because only average diode current can be measured. Quite often, the average current is zero while high peak currents are existing. The presence of anomalous current is obvious in our investigation because of the significant noise factor increase in raising the gain of the signal only 1 db.

Future effort on the balanced-diode mount will be directed toward lowering the noise factor by using diodes with higher cut-off frequencies. An attempt will also be made to raise the gain-bandwidth product further, by using diodes with greater nonlinearity ratios.

C. VARACTOR DIODES

During the past quarter, SOLRAC varactors and Microwave Associates varactors have been used in the balanced- and unbalanced-diode mounts. Generally, the Microwave Associates diode appears to be the better diode for broadband low-noise applications; however, the parasitic case capacitance of this diode seems to be a limiting factor. At the present time, Microwave Associates is conducting a program for the fabrication of ten sample varactor diodes that have lower case capacitances and high cut-off fre-

quencies. It is hoped that these diodes will enhance the present performance of the balanced-diode mount.

Thus far, the SOLRAC diode has not yielded a significant amount of gain or bandwidth. Therefore, in view of the encouraging results obtained from the Microwave Associates diode, only limited engineering effort will be expended on the SOLRAC diode.

III. CONCLUSIONS

In view of the practical data obtained during the last quarter, it now appears that neither the mount nor the circulators are limiting further increases in bandwidth and gain and reductions in noise factor. The varactor diode itself is the limitation. Fortunately, Microwave Associates is aware of this problem and has volunteered their cooperation in improving varactor performance through whatever suggestions we can offer.

IV. PROGRAM FOR NEXT INTERVAL

Engineering effort during the next quarter will be directed toward evaluating the noise factor and gain of a staggered pair of single-diode mounts over a 40-percent bandwidth. In addition, the performance of ten sample low-capacitance high cut-off frequency varactor diodes will be evaluated using the balanced-diode mount.

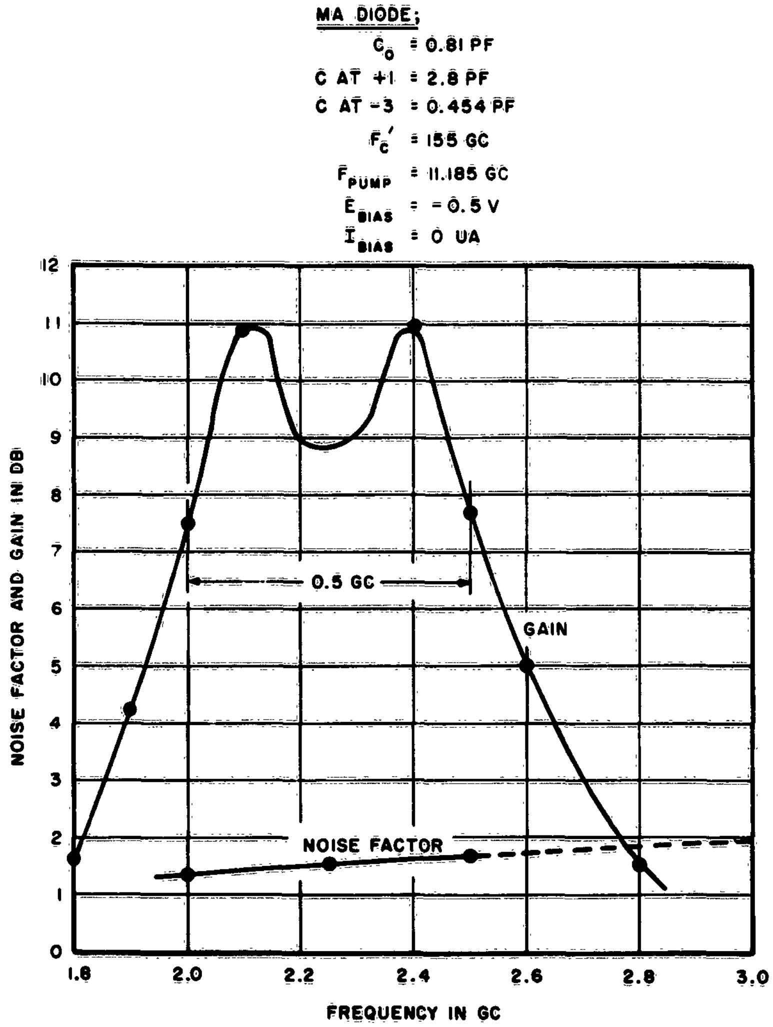

FIGURE 1. GAIN AND NOISE FACTOR AS A FUNCTION OF FREQUENCY FOR ONE SINGLE-DIODE MOUNT USING DOUBLE TUNING

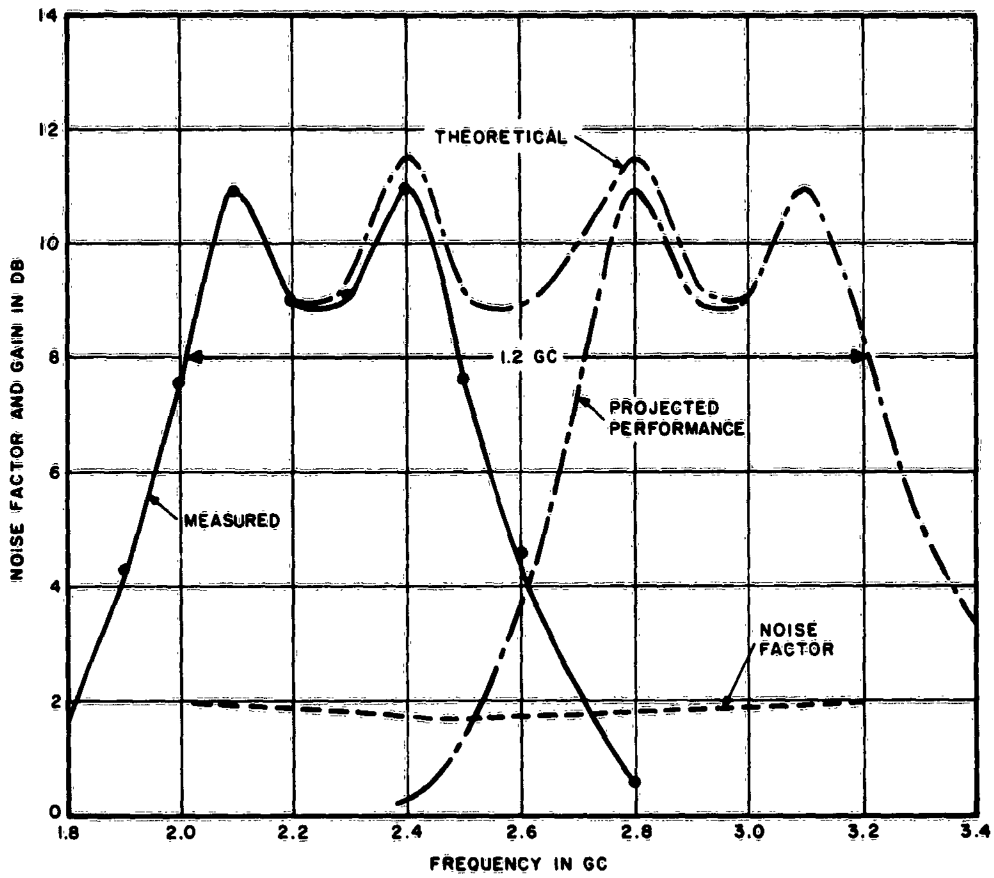

FIGURE 2. THEORETICAL GAIN AND NOISE FACTOR AS A FUNCTION OF FREQUENCY FOR TWO STAGGERED SINGLE-DIODE MOUNTS

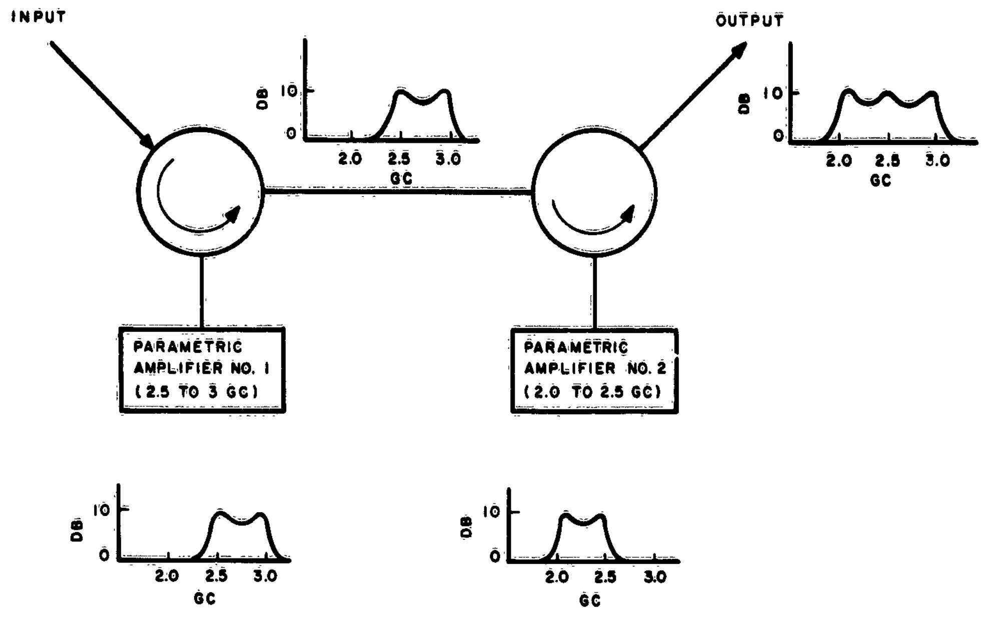

FIGURE 3. AMPLIFIER CONNECTION

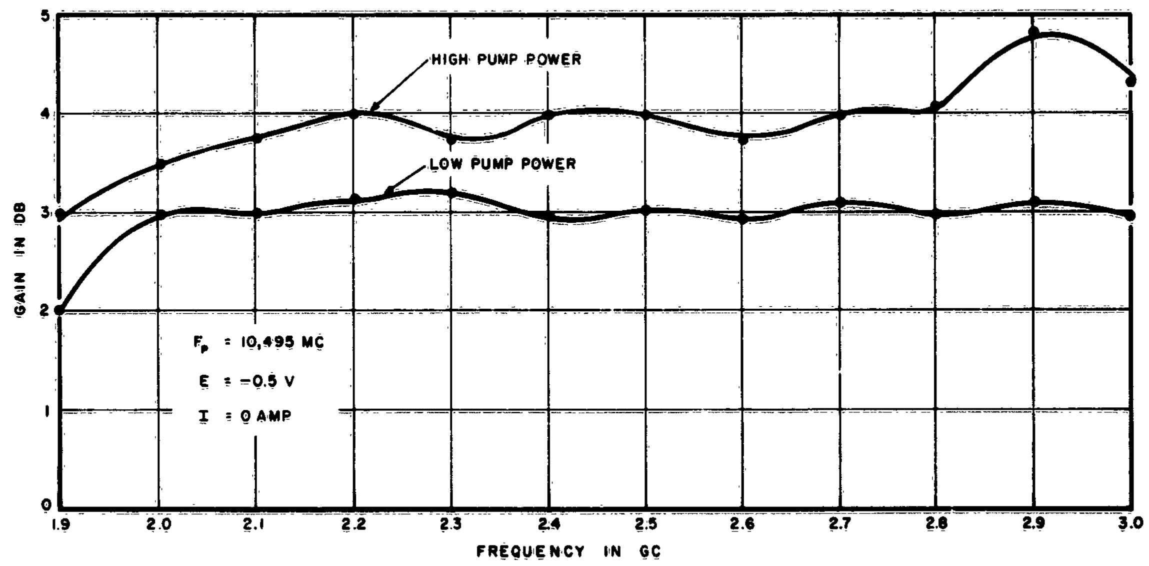

FIGURE 4. GAIN AS A FUNCTION OF FREQUENCY FOR ONE BALANCED-DIODE MOUNT USING DOUBLE TUNING

DISTRIBUTION LIST FOR REPORT NO. 2097-I-2

	Quarterly	Final
Commanding Officer and Director U. S. Navy Electronics Laboratory San Diego 52, California	1	1
Commander Aeronautical Systems Division Wright-Patterson Air Force Base, Ohio ATTN: Code WWRN	2	1
Commanding Officer Diamond Ordnance Fuze Laboratories Electron Tube Branch Washington 25, D. C.	1	1
Commanding Officer U. S. Army Signal Research and Development Laboratory Electron Devices Division Fort Monmouth, New Jersey	2	1
Commander New York Naval Shipyard Material Laboratory, Code 923 Naval Base Brooklyn 1, New York	1	1
Chief, Bureau of Ships Department of the Navy Washington 25, D. C.		
ATTN: Code 681A1D	1	1
Code 335	4	4
Director U. S. Naval Research Laboratory Washington 25, D. C.		
ATTN: Code 5240, Dr. S. T. Smith	1	1
Library	2	2
Advisory Group on Electron Devices 346 Broadway, 8th Floor New York 13, New York	3	3

	Quarterly	Final
Commanding General Rome Air Development Center Griffiss Air Force Base, New York ATTN: Documents Library, RCSSTL-1	1	1
Code RCERA-1	1	1
Commander, Armed Services Technical Information Agency Arlington Hall Station Arlington 12, Virginia	10	10